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Assessment of Air Contamination in Mosul University Campus Using Remote Sensing and GIS Techniques

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ABSTRACT

Air pollution is a significant problem in densely populated areas such as the university campus. This study investigates the spatial levels and distribution of air pollutants within the University of Mosul campus. A special measuring device is used with remote sensing and Geographic Information Systems (GIS) data. Ground-level monitoring data assesses major pollutants such as particulate matter (PM2.5 and PM10) and other gases. Satellite images and digital elevation models (DEMs) are processed to extract spatial distribution information of pollutant concentrations and to learn about the effects of terrain. GIS techniques analyze spatial patterns and correlations between pollutant levels and different campus features, such as transportation routes and green spaces. Ground-level monitoring stations are strategically placed throughout the campus to validate the results. The results cover the winter 2023, spring 2024, and summer 2024 periods at 16 selected locations. The results show higher concentrations of PM2.5 and PM10 in spring compared to summer and winter, with values of 30.594 µg/m³ and 40.298 µg/m³, respectively. The highest concentrations are observed at the main entrances of the campus due to increased traffic. PM2.5 levels exceeded both the Iraqi limit and the WHO standard of 10 µg/m³, while PM10 concentrations exceeded the WHO limit of 20 µg/m³ but within the Iraqi limit of 50 µg/m³. This research contributes to effective environmental monitoring methodologies and highlights the importance of innovative techniques for assessing air pollution in educational institutions and urban environments.

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تقييم تلوث الهواء في حرم جامعة الموصل باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية

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الملخص

يعد تلوث الهواء مشكلة بالغة الأهمية في المناطق ذات الكثافة السكانية العالية مثل الحرم الجامعي. تبحث هذه الدراسة في كشف مستويات وتوزيع الملوثات الجوية المكانية داخل حرم جامعة الموصل. تم استخدام جهاز قياس خاص مع بيانات الاستشعار عن بعد ونظم المعلومات الجغرافية (GIS). تقوم بيانات الرصد على مستوى الأرض بتقييم الملوثات الرئيسة مثل الجسيمات (PM2.5 و PM10) والغازات الأخرى. تتم معالجة صور الأقمار الصناعية ونماذج الارتفاع الرقمية (DEM) لاستخلاص معلومات التوزيع المكاني لتركيزات الملوثات ولمعرفة تأثيرات التضاريس. تحلل تقنيات نظم المعلومات الجغرافية الأنماط المكانية والارتباطات بين مستويات الملوثات وميزات الحرم الجامعي المختلفة مثل طرق النقل والمساحات الخضراء. تم وضع محطات الرصد على مستوى الأرض بشكل استراتيجي في جميع أنحاء الحرم الجامعي للتحقق من صحة النتائج. غطت النتائج فترات الشتاء 2023 والربيع 2024 والصيف 2024 في 16 موقعًا مختارًا. اشارت النتائج إلى ارتفاع تراكيز الجسيمات PM2.5 و PM10 في الربيع مقارنة بالصيف والشتاء بقيم 30.594 ميكروغرام/م^3 و 40.298 ميكروغرام/م^3 على التوالي. وقد لوحظت أعلى التراكيز عند المداخل الرئيسة للحرم الجامعي بسبب زيادة حركة المرور. تتجاوز مستويات PM2.5 كلاً من الحد العراقي ومعيار منظمة الصحة العالمية البالغ 10 ميكروغرام/م^3، في حين تتجاوز تراكيز PM10 حد منظمة الصحة العالمية البالغ 20 ميكروغرام/م^3 ولكنها ضمن الحدود العراقية البالغة 50 ميكروغرام/م^3. يساهم هذا البحث في منهجيات مراقبة بيئية فعالة ويسلط الضوء على أهمية التقنيات المبتكرة لتقييم تلوث الهواء في المؤسسات التعليمية والبيئات الحضرية.

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Introduction

Pollution is defined as the introduction of pollutants into the environment that are toxic to humans and other living organisms. Pollutants are toxic solids, liquids, or gases created in larger amounts than usual, lowering the quality of our environment (Ioannis et al., 2020). Air pollution primarily affects urban areas, with traffic emissions being the primary contributor to poor air quality (Al-Hayani and Thanoon, 2025). Toxic fog from industrial mishaps might pose a risk to nearby communities. Pollution dispersal depends on several factors, including atmospheric stability and wind (Sathya et al., 2023). Numerous contaminants play a significant role in human diseases. Among these, inhaled particulate matter (PM) which refers to a mixture of solid particles and liquid droplets prevalent in the air. Dust, grime, soot, and smoke are some of the larger or darker particles that can be seen with the naked eye. Others are so minuscule that they can only be detected using an electron microscope (Carvalho et al., 2018). Inhaled particulates of PM can cause oxidative stress and inflammation in the brain directly through the nose or indirectly through reactions in the peripheral nervous system. Other pollutants are dioxins, sulfur dioxide, nitrogen oxides, dioxin-containing volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), are all regarded as hazardous air pollutants for human health. Air pollution produces significant health risks and environmental concerns in urban areas (World Health Organization, 2021), including university campuses. With the increasing awareness of the adverse effects of air pollution on human health and the environment, there is a growing need for efficient monitoring and assessment strategies and techniques (Amina et al., 2022). The WHO and EPA established air quality guidelines and criteria for various pollutants as a means of managing air quality (WHO, 2024; NEPIS, 2017). To identify the trouble spots, these criteria need to be matched to the emissions inventory standards using dispersion modeling and causal analysis. In general, direct measurements and emissions modeling are used to create inventories. Recently, remote sensing and Geographic Information Systems (GIS) have emerged as powerful tools for studying air quality, offering spatially explicit data and analytical capabilities to identify sources of pollution and assess their impacts (Faezeh et al., 2024; Amina et al., 2022). Remote sensing provides a non-invasive means of acquiring data over large areas, enabling the detection of air pollution hotspots, such as vehicular emissions, industrial facilities, and biomass burning (Huang et al., 2020). Remote sensing satellites have been using algorithms to estimate pollutant levels, including PM 2.5, based on optical properties. Therefore, local measurements can help in making comparisons and improving these algorithms, increasing the effectiveness of verification and reducing expected errors. Through the analysis of satellite imagery, pollutants like particulate matter (PM) and Carbon dioxide (CO_2) can be quantified and mapped with high spatial resolution (Sabah et al., 2023). GIS serves as a robust platform for integrating, visualizing, and analyzing spatial data obtained from remote sensing and ground-based monitoring stations.

In Amina et al. (2022), PM2.5 and PM10 concentrations were measured in different areas of Mosul City from September 2020 to February 2021 in 10 locations, executed by the IDW interpolation method in GIS. The results showed levels above the WHO limits of PM2.5 and PM10.

Al-Jarrah (2015) used air pollution measuring devices to measure concentrations of pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), ground-level ozone (O3), and fine particles (such as PM10 and PM2.5). The results of the study indicated a strong relationship between air pollution levels and traffic volume, as levels of pollutants such as PM10 and CO increased in locations with heavy traffic. Climate data also showed an effect on the concentration of these pollutants.

The current study focuses on the application of remote sensing and GIS techniques for assessing air contamination with PM2.5 and PM10 within the Mosul University campus environment. University campuses, characterized by diverse activities and infrastructure, represent microcosms of urban environments with unique air quality challenges. By leveraging satellite data and ground-based sensors, coupled with GIS-based spatial analysis, we aim to comprehensively evaluate the spatial distribution and temporal variation of air pollutants across the campus by overlaying pollution maps with land use/land cover data and meteorological parameters (Younis, 2021). GIS facilitates the identification of vulnerable areas within the campus and the characterization of exposure risks to different population groups (Tikader et al., 2023). Furthermore, GIS-based modeling techniques, such as dispersion modeling and spatial interpolation, allow for the prediction of pollutant concentrations at unmonitored locations.

Materials and Methods

Study Area and Topography

The University of Mosul is located within the city of Mosul, in northern Iraq at the geographical coordinates of Latitude (360:22':25.10" – 36^0:23':35.40") N and Longitude (430:07':37.10" – 43^0:09':11.40") E, Figure. 1. The first building blocks of the construction of

Mosul University date back to 1959 AD, the year when the Faculty of Medicine began its first academic year in Mosul, but the actual appearance of Mosul University was as a scientific educational institution based on the ground dating back to April 1 of the year 1967 AD (Al-Heety et al. 2022). The University of Mosul is known for its rich academic reputation. It includes (24) colleges and (7) research centers. The University covers a large area of about 2.544 km^2. The University has a large student population, estimated at approximately 75,000 male and female students (Mahmood et al. 2020).

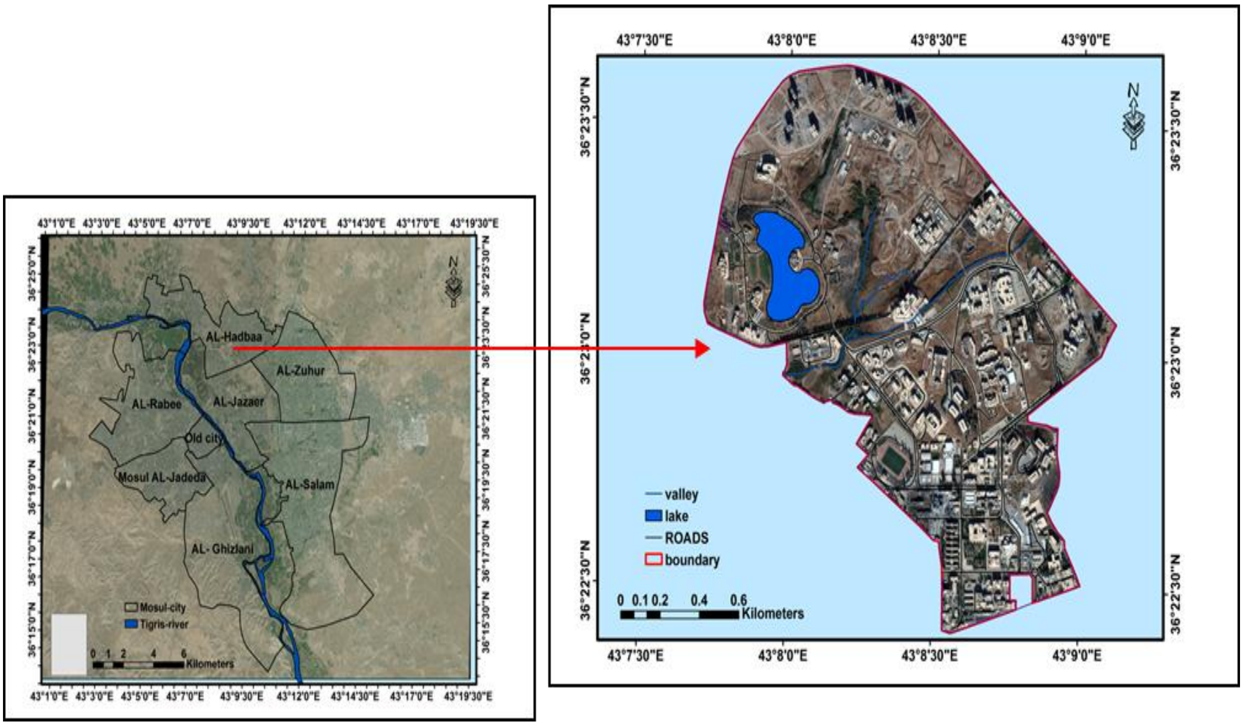

Fig. 1. Study Area: Mosul University (Source: Organized by authors).

The topography elevation for Mosul University has a spatial contrast, as shown in Figure 2. According to the adopted Digital Elevation Model (DEM) with a spatial resolution of 30m, the elevation varies from 235 meters in the south to 269 meters in the north and northeast. The Al-Kharazi Valley is the main course with its tributaries, which dominates the topography of the study area through the vertical drilling of this network and its impact on the morphology of the terrain.

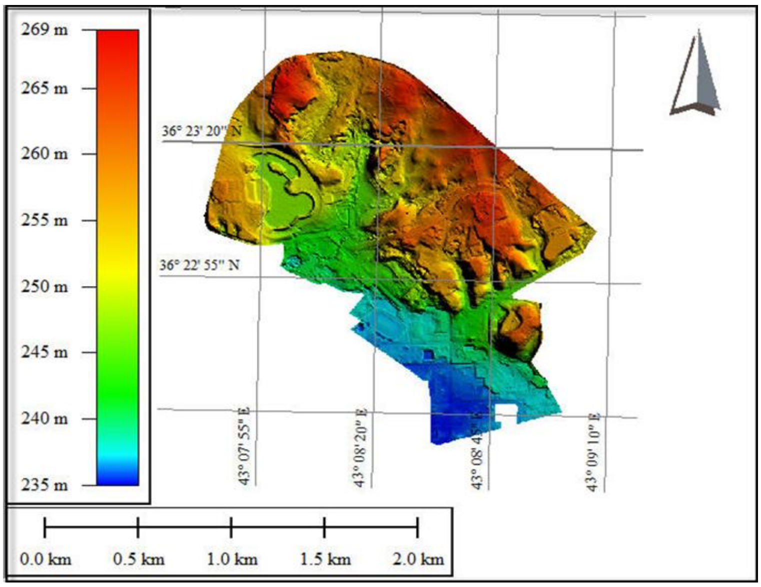

Fig. 2. Topographic aspect of Mosul University.

Data Collection and Method

Due to its central location, Mosul University experiences a constant flow of vehicular traffic. The number of cars entering the university daily can vary; it will reach more than 9728 vehicles in 2024, as statistically documented in the presidency of Mosul University, given the volume of students and staff, as well as the ongoing activities taking place within its buildings. Vehicles emit many pollutants into the air, including carbon monoxide, carbon dioxide, hydrocarbons, nitrogen oxides, sulfur oxides, and volatile organic compounds. These pollutants then combine to form secondary pollutants such as fine particulate matter (PM2.5, PM10) and ozone (Henna et al. 2024). In this study, the portable device (Temtop M2000/ American Elitech Technology) was used to measure the concentration of PM in the field at the selected sites on the Mosul University campus, Figure.3. The device depends on the principle of dynamic light scattering (DLS) technology, which is a technique to determine the size of the particles by using random changes in the intensity of light spread across the air (Ren et al. 2020). The device captures the spread light at a given angle to measure the concentrations of the trapped particles PM2.5 and PM10 in the surrounding air and converts it into visual data that displays directly on the device screen with a unit of ($\mu g/m^3$) (Mahmood et al. 2020). WorldView-2 satellite imagery with natural color bands (2, 3, 5) was used to identify particulate matter (PM) concentration levels across a selected site in the university campus. This high-resolution satellite imagery, equipped with advanced multispectral imagery with eight bands, Table 1.

Fig. 3. Temtop M2000 device.

Table 1: Worldview2 spectral bands (https://earth.esa.int/eogateway/missions/worldview-2).

Band no.	Description	Spectral Resolutions (nm)	Spatial Resolution
1	Coastal blue	400-450	1.85 m
Used 2	Blue	450-510	
Used 3	Green	510-580	
4	Yellow	585-625	
Used 5	Red	630-690	
6	Red-edge	705-745	
7	NIR1	770-895	
8	NIR2	860-1040	
Panchromatic band		450-800	46 cm

All the (16) selected sites were identified using GPS map 76CSx by geographical coordinate system (latitude and longitude). Figure 4 illustrates the location of the selected sites on campus; most chosen locations suffer from traffic congestion, which contributes to the emission of gases and particulate matter from the vehicles' exhaust. Table 1 lists the numbers, longitude, latitude, and the PM2.5 and PM10 concentrations readout for each site indicated in Figure 4. Three periods were adopted in measuring the seasonal average of the PM2.5 and PM10 (Winter, 2023, and Spring, Summer, 2024).

Fig. 4. The selected sites in Mosul University campus (Worldview2 image, natural color bands 2,3, and 5).

The Geographical Information System (GIS) includes analytical method which are very useful in the geographical distribution of environmental features, such as air pollution monitoring data, studying the causes of problems, and developing prevention strategies (Jumaah et al. 2019). Linking different types of data, such as PM2.5 and PM10, is useful with GIS. In the present study, to create surface maps for PM10 and PM2.5 concentrations, the measurement dataset listed in Table 1 was spatially analyzed by using ArcGIS 10.6.1. The Inverse Distance Weight (IDW) interpolation method was extended to the entire surface of the study area for the seasons of Winter 2023, Spring 2024, and Summer 2024. One advantage of the IDW technique is that it maintains the measured value at the sample site and assumes that sample points closer to the cell have a higher impact on the cell's estimated value than sample points farther away, this is in line with the dispersion of air pollution, where nearby sources have a greater impact on PM2.5 levels (Sabah et al. 2018) (Kanghyeok 2022). The concentrations of each particulate matter, as well as the associated distribution of the particles and their concentration, could be analyzed and classified using the interpolated surface of the PM2.5 and PM10 for each site in the study region for each month. Figure 5 illustrates the flow chart of the methodology applied in the current study.

Table 1: Temtop M2000 device and GPS readouts for each site.

No.	Site names	Longitude (degree)	Latitude (degree)	Winter 12/2023		Spring 3/2024		Summer 6/2024	
				PM2.5 μg/m^3	PM10 μg/m^3	PM2.5 μg/m^3	PM10 μg/m^3	PM2.5 μg/m^3	PM10 μg/m^3
1	College of Medicine	43.131	36.3901	16.8	22.3	21.2	27.7	15.2	23.6
2	Main entrance (College of Agriculture)	43.1303	36.3877	19.2	27.9	26.8	32.9	15.1	25.3
3	Entrance to Palaces (University Press)	43.136	36.3842	15.3	25.4	24.5	29.7	13.7	21.6
4	University Presidency Building	43.1376	36.3827	13.9	23.8	22.5	28.5	15.8	25.4
5	Intersection of Environmental Sciences College	43.1416	36.3845	14.9	26.5	23.8	31.8	17.8	27.4
6	Main entrance (College of Medicine gate)	43.1464	36.3882	19.4	32.8	27.1	36.7	19.7	29.2
7	Main entrance (College of Engineering)	43.1478	36.3756	14.8	24.8	22.5	28.7	18.3	27.3
8	College Dentistry Intersection	43.1471	36.3855	15.1	23.6	24.1	27.6	15.2	24.6
9	Student Center Junction - College of Education	43.1447	36.3775	17.2	27.3	26.5	35.4	16.4	26.6
10	College of Science Junction	43.1436	36.3756	19.7	30.5	30.6	37.9	17.1	26
11	Transport Car Park (College of Computer Science and Mathematics)	43.1461	36.3776	16.8	33.5	28.4	39.1	20.7	32.1
12	Nursery junction	43.1432	36.3786	17.9	31.8	25.9	39.9	21.7	34.8
13	Intersection of Arts College and female internal sections	43.1443	36.3805	16.5	33.9	26.3	41.3	24.9	36.7
14	External car parking (Girls Education College)	43.1404	36.3805	15.1	26.8	24.6	34.8	16.3	27.9
15	Car Parking (Scientific and Literary Forum Building)	43.1311	36.3846	14.7	23.7	22.3	30.6	14.7	23.1
16	Erbil and Duhok car parking (University bank intersection)	43.1434	36.3775	17.2	31.1	29.2	38.7	20.5	32.1

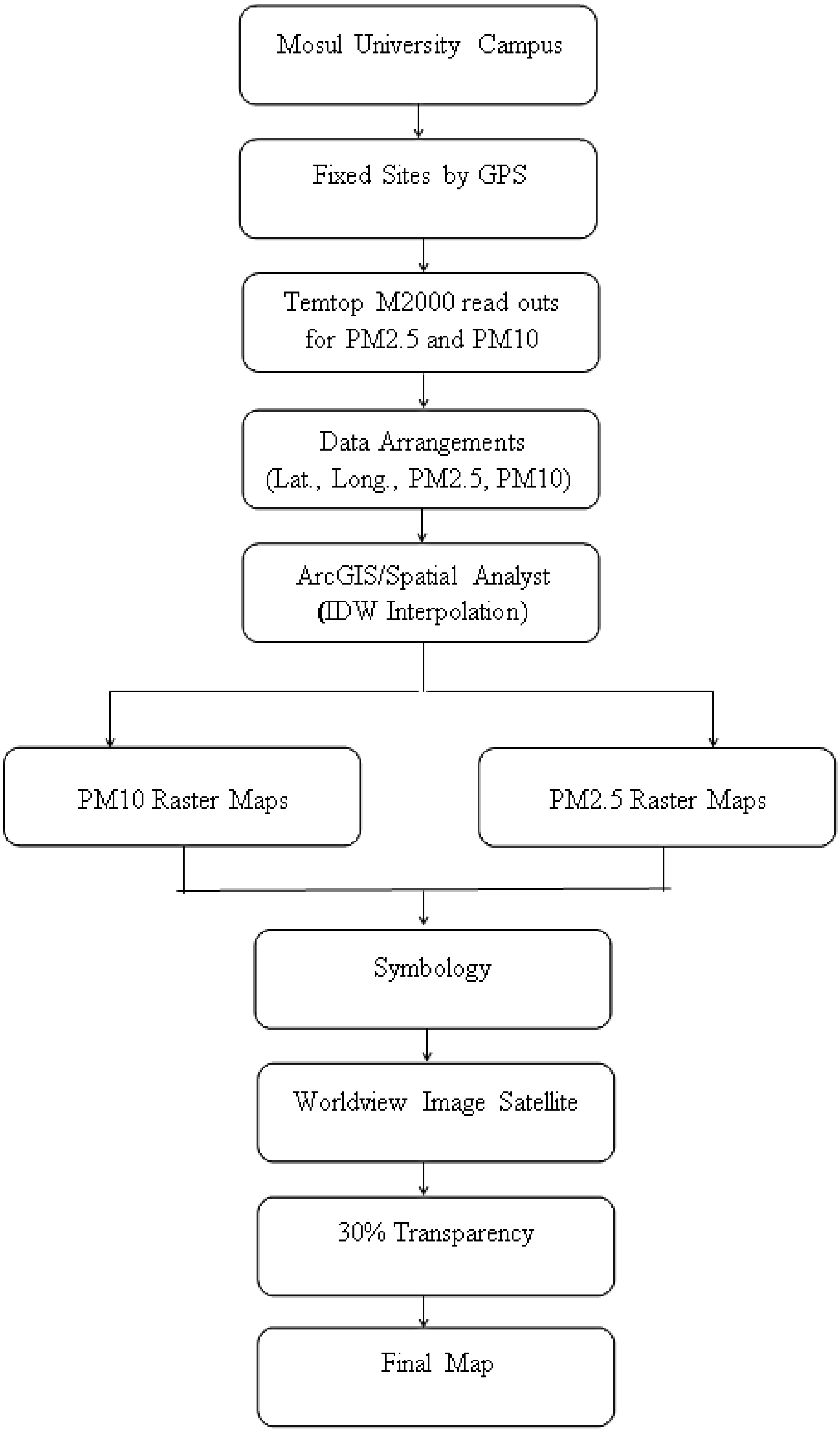

Fig. 5. Flow chart of the adopted methodology.

Results and Discussion

Seasonal changes in the weather cause spatial variations in PM2.5 and PM10 concentrations. Weather and PM emissions are both subject to change. Generally, the climate of the study region is similar to that of Mosul city, which means: a hot and dry Summer (June, July, and August), cool and rainy Winter (December, January, and February), Transitional Spring (March, April, and May), and Autumn (September, October, and November). Figures 6 and 7 depict PM2.5 and PM10 spatial distribution on the Mosul university campus, respectively, as a function of the Winter 2023, Spring 2024, and Summer 2024 seasons. The figures depict the levels of PM2.5 and PM10 based on the high number of vehicles on campus, which are related to the working hours of lecturers, students, administrative, and other technical staff as issued by the Ministry of Higher Education and Scientific Research's yearly university calendar.

However, Figure 6 shows the spatial and temporal distribution of the PM2.5 concentrations. The highest concentration of PM2.5 particles is seen in the spring season, specifically at site (10), which is one of the main entrances to the university campus, due to the increased traffic from cars within the campus during the spring semester, and also due to student activities. Site (10) is located near a commercial street and is surrounded by several colleges and scientific departments, as well as a lack of green spaces. In contrast, the concentration levels of PM2.5 are generally low in other sites, particularly in the northwestern part of the campus known as the Palaces Complex. This area has fewer buildings, fewer student activities, less traffic congestion, and the presence of green spaces and a lake.

The spring season is a transitional season characterized by weather fluctuations, such as rain showers and moderate temperatures. Additionally, there is a spring break for students and faculty. In the summer season, official work was suspended for students, staff, and faculty, resulting in decreased car traffic within the university campus and consequently lower levels of pollution of PM2.5. Figure 6 also indicates that most areas of the campus are relatively free of pollution, except for certain sites like site (13) and its surroundings. Site (13) serves as an intersection point for cars from the Faculty of Arts and the student dormitories. It is also home to a university shopping center, which contributes to the highest pollution concentration recorded in this area (24.89 $\mu g/m^3$).

It is important to note that high temperatures during summer lead to increased evaporation of moisture, which in turn dries dust particles and reduces their weight. This leads to a wider spread of particles in areas with high pollution resulting from heavy traffic (Giang et al. 2023). In winter, rain acts as a purifier, cleansing the air from PM2.5. Some of these particles serve as condensation nuclei, where water vapor condenses on them and causes them to fall; others are washed away by rain (Al-Jarrah 2015). Consequently, the levels of PM2.5 concentrations decrease in most locations of the study area during winter. The highest concentration value (19.69 $\mu g/m^3$) was observed at locations (2, 6, and 10), which are the main entrances for cars to the university campus. It is important to note that winter is a season with full official working hours for faculty, staff, and students.

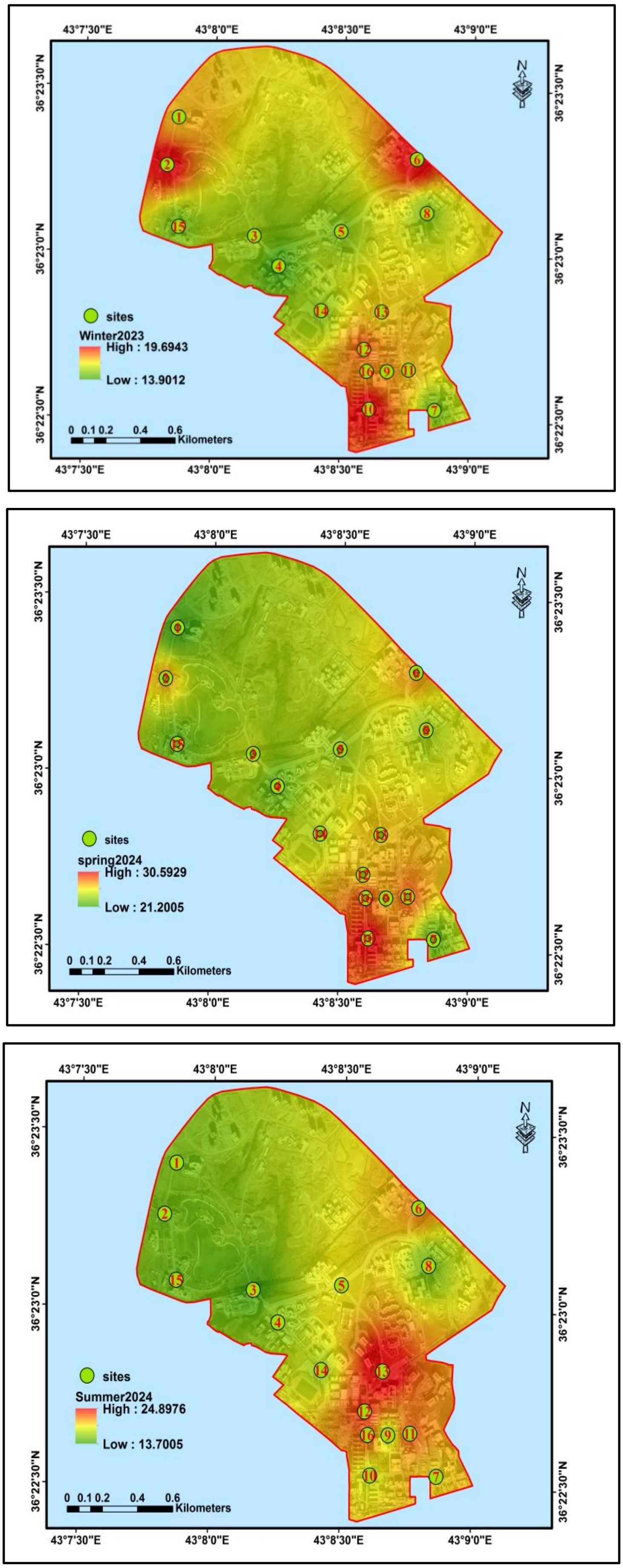

Fig. 6. Seasonal spatial distribution of the PM2.5 concentration.

This research-based case study also examines the seasonal spatial distribution of PM10 within the university campus. Figure 7 provides a visual representation of this distribution, while Table 2 presents relevant data. Upon analyzing the figure and table, it is evident that the concentration level of PM10 particles is higher compared to PM2.5 particles across all seasons considered in this study. However, there is a notable similarity in the spatial and temporal distribution patterns, particularly during the spring and summer seasons. Regarding the seasonal spatial distribution of PM10 particles, it is noteworthy that the concentration is highest during the spring season, reaching a value of (41.2981 µg/m^3). On the other hand, the concentration is lowest during the winter season, reaching a value of (33.8983 µg/m^3). Additionally, it is observed that the northwestern part of the university campus, which includes the palace complex, exhibits the lowest concentration level, as shown in the locations (1, 2, 3, and 15). This area is characterized by abundant vegetation, few buildings, traffic congestion, and the presence of a lake site. While the locations (11, 12, 13, and 16) are characterized by high student activity and heavy traffic.

It is important to highlight that PM2.5 particles are fine particles that remain suspended in the air for extended periods and cover relatively large areas. These particles tend to carry harmful substances on their surface, posing a greater risk to human health. In contrast, PM10 particles, being larger in diameter than PM2.5 particles, do not remain suspended in the air for as long. Their spread is limited, as they tend to settle on the ground. As a result, the presence of PM2.5 particles poses a greater danger to human respiratory health, including the development of conditions such as asthma and pneumonia (Qiaofeng and Meiping 2022). Finally, remote sensing satellites commonly use algorithms to estimate PM2.5 levels based on optical characteristics to estimate the PM concentration levels. As a result, local measurements can assist in enhancing these algorithms and reducing expected errors (Imas et al. 2023). From the observation of the results, it is clear that the heights read from the DEM played a different role, but it was not significant during the seasons studied. So, it may be an important factor in the summer, but it also shows that there is noticeable pollution during the winter at the site (6), which proves that pollution depends on the causes of pollutants, such as the large number of cars, and that the height is not a decisive factor.

Based on the recommended national ambient air quality guidelines in Iraq, all seasonal average PM2.5 values exceed both the Iraqi limit level and the World Health Organization (WHO) standard (10 µg/m^3) (WHO 2006), as shown in Figure 8. Additionally, PM10 concentration level exceeds the WHO standard limits of (20 µg/m^3), but falls within Iraqi standard limits of (50 µg/$m^{3)}$ (JICA 2011), as shown in Figure 9.

Recommendations

Recommendations to improve the atmosphere of the Mosul University large campus and reduce gas emissions that are harmful to human health:

1. Expanding green spaces: It is recommended to plant more trees and plants throughout the campus, as green spaces play an important role in improving air quality and reducing pollution rates.
2. Encouraging sustainable transportation: Special bicycle paths should be created, and safe areas should be provided for parking them, in addition to promoting the use of public transportation within the campus to reduce reliance on private cars.
3. Implementing environmental awareness programs: It is recommended to launch awareness campaigns for students and employees on the importance of preserving the environment and reducing pollution, which contributes to changing daily behaviors for the better.
4. Improving the waste management system: It is recommended to implement an effective waste management system that includes recycling and proper waste disposal, which reduces the emission of harmful gases resulting from burning waste.

5. Adopting renewable energy: It is recommended to use renewable energy sources, such as solar energy, to generate electricity on campus, which contributes to reducing carbon emissions.

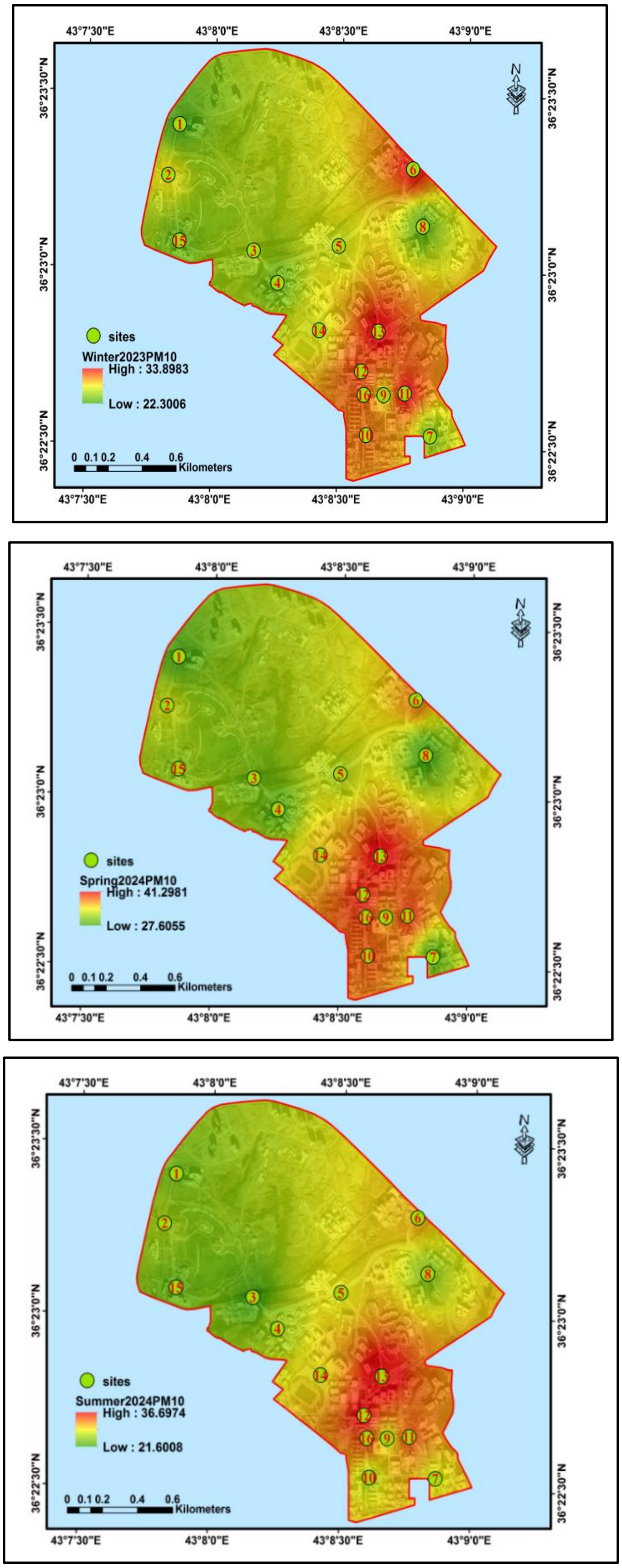

Fig. 7. Seasonal spatial distribution of the PM10 concentration.

Table 2: Min. and Max. values of PM2.5 and PM10.

Type	Min. value μg/m³			Max. value μg/m³		
	Winter	Spring	Summer	Winter	Spring	Summer
PM2.5	13.9012	21.2005	13.7005	19.6943	30.5929	24.8976
PM10	22.3006	27.6055	21.6006	33.8983	41.2981	36.6974

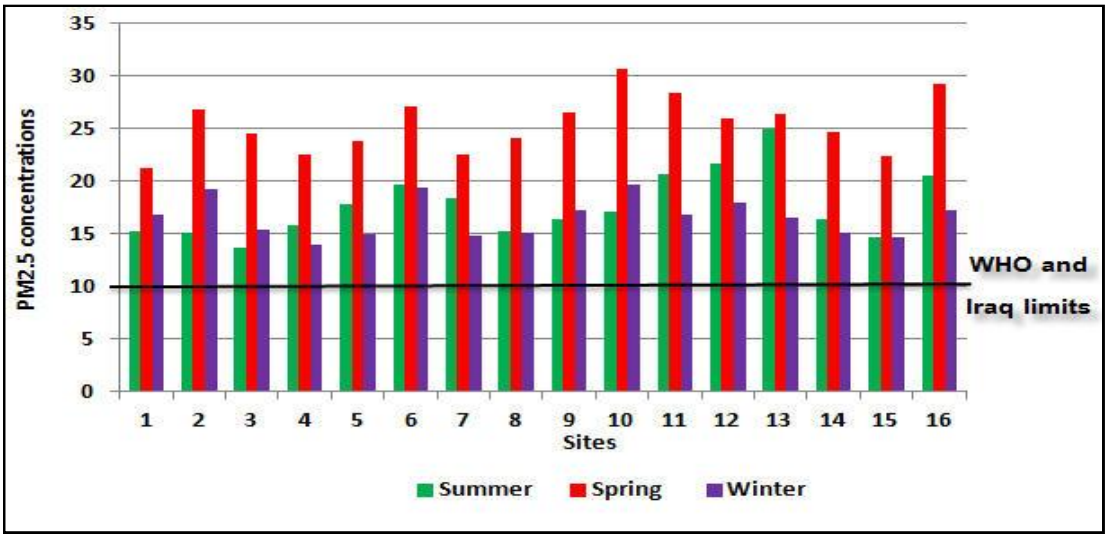

Fig. 8. PM2.5 concentrations with respect to WHO and Iraqi standards.

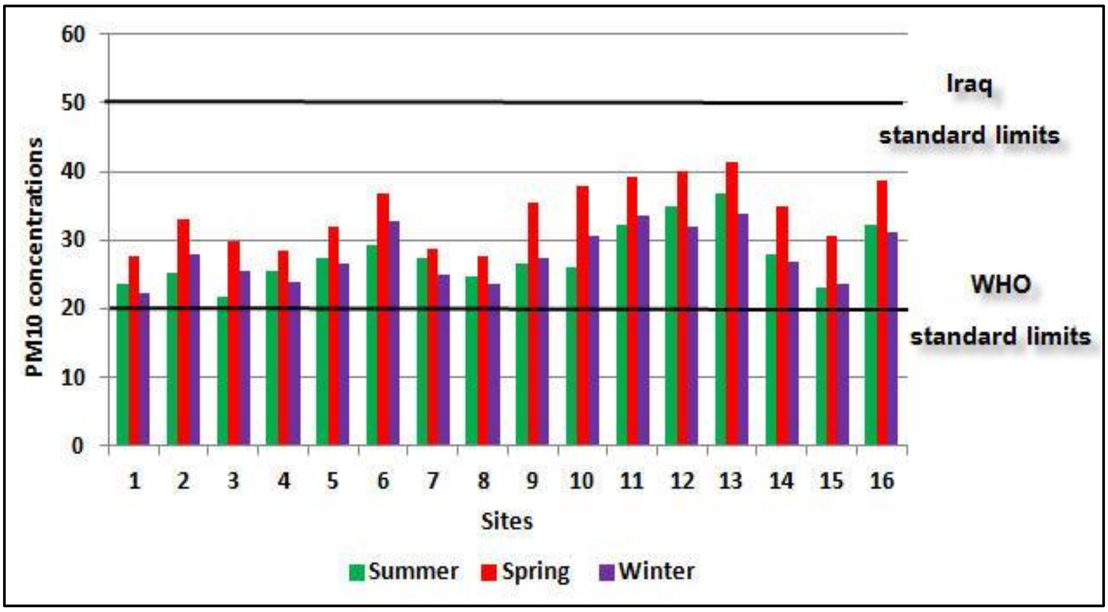

Fig. 9. PM10 concentrations with respect to WHO and Iraqi standards.

6. Providing air purifiers: It is preferable to install air purifiers in university buildings to ensure improved indoor air quality and reduce the impact of pollutants on the health of students and employees.

By implementing these recommendations, the atmosphere at Mosul University can be improved, and the health of the university community can be enhanced.

Conclusions

The current paper investigates the Temporal and Spatial distribution of PM2.5 and PM10 concentration levels inside the Mosul University Campus/Iraq for the seasons (Winter 2023, Spring 2024, and Summer 2024), and the following conclusions are drawn:

1- The highest concentration of PM2.5 and PM10 particles in Spring was seen to be higher than in the Summer and Winter seasons due to the increased traffic from cars within the campus during the spring semester, also due to student activities.
2- In the summer season, official work was suspended for students, staff, and faculty, resulting in decreased car traffic within the university campus and consequently lower levels of pollution of PM2.5 and PM10.
3- In winter, the levels of PM2.5 and PM10 concentrations decreased in most sites of the study area because the rain acts as a purifier and cleans the air from particulate matter. Winter is a season with full official working hours for faculty, staff, and students.
4- Generally, the concentration values of PM10 particles are higher compared to PM2.5 particles across all seasons considered in this study.
5- The highest concentration values of PM2.5 and PM10 particles were seen in the main entrances to the university campus due to the increased traffic.
6- All seasonal average PM2.5 values exceed both the Iraqi limit level and the WHO standard (10 $\mu g/m^3$), while PM10 concentration levels exceed the WHO standard limits of (20 µg/m3), but fall within Iraqi standard limits of (50 $\mu g/m^3$).

The study supported attempts to enhance air quality and establish better living and learning environments by offering insightful information on the Mosul University campus environmental conditions and presented several recommendations that the university authority should undertake in this regard.

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